PIPING NETWORK END-USER MANUAL-SAMPLE

CENTER OF NUMERICAL ANALYSIS TECHNOLOGY

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1 INTRODUCTION

Any produced or collected fluid requires transportation and/or distribution to targeted nodes or end users. In many occasions, there are multiple discharge points that receive fluid from one single source or multiple sources. The transporting/distributing system that transfers fluid between source and target spots forms a piping/duct network that can be as simple as one pipeline and as complex as a multi-nodal network with branches and loops. Examples of such systems are, municipal water system, plumbing network of a house, plumbing system of a multi-story building, central A/C ducting, sprinkler system, piping system of a refinery or an industrial plant; and so on. When constructing such a piping network, it is crucial to assure that terminal nodes (whether discharge or source) are set to required flowrates and/or pressures regardless of network complexity and branching that connect these terminal nodes.

As a result, piping network designers are always required to analyze the hydraulic performance of the proposed-designed network prior to construction to assure that the network achieves the set-forth conditions at the terminal nodes.

1.1 Purpose of Document

This document is developed as a manual for the designer/analyst to perform detailed calculations of the pressure and flowrate distribution over a piping network including its branches, junctional nodes (defined as nodes each is connected to multiple branches) and terminal nodes (defined as nodes each is connected to a single branch). A schematic of a network considered in this document is illustrated in Figure 1-1. The steps in this document will guide the designer/analyst to the procedure and the scientific basis used in satisfying flowrate and pressure balances over the network.
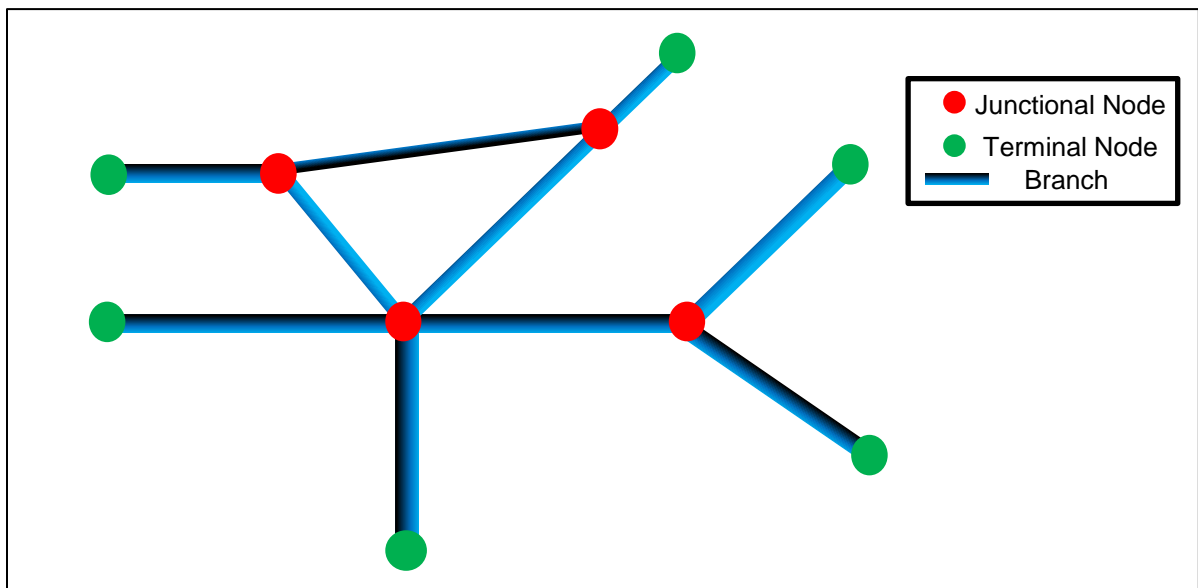

Figure 1-1: A schematic of a piping network

1.2 Focus of Document

This document will focus on the following criteria for the piping network analysis:

- The fluid within the network is always considered Newtonian and single-phased with incompressible, steady and fully-developed flow.
- The piping network branches are pre-defined for circular cross-sections and configured in terms of diameters, lengths and their end-nodes' elevations.
- The terminal nodes' flow conditions (such as pressures, volumetric flowrates or a combination of both) are pre-set as boundary conditions. i.e. the analysis determines the flowrates at terminal nodes with pre-set pressures and determines pressures at terminal nodes with pre-set flowrates.
- No limitations on the network configuration or complexity. i.e. the analysis is capable of handling random network configurations with random number of branches and nodes under the condition that, at least one junctional node is present within the network.
- No effect of temperature changes is considered.
- One common inner surface roughness is applied over the network components.
- Friction losses due to roughness are the only considered losses. i.e., minor losses are accounted for in this document.

1.3 Units and Dimensions

All units and dimensions are applicable in this document. All variables and parameters must be defined on the basis of the same units system. This document does not account for unit conversion.

2 SYMBOLS AND ABBREVIATIONS

Below is a list of symbols and abbreviations that are used in this document. Other specific symbols and abbreviations, if any, will be defined in place.

g	: Gravitational acceleration.
h_i	: Head drop along the ith branch
H_i	: Elevation head at the jth node
ID_i	: The inner diameter of the ith branch
itermax	: Maximum number of iterations set for any iterative process
L_i	: Length of the ith branch
n	: Number of branches
nam-i	: Name of the ith branch
nd	: Number of nodes within the network
nd_in-i	: The ith branch inlet node index
nd_out-i	: The ith branch outlet node index
ns_i	: The ith branch boundary condition index
pf_in-i	: The ith branch inlet node boundary condition
pf_out-i	: The ith branch outlet node boundary condition
P_i	: Absolute pressure of the jth node
$\dot{Q}_i$	: Volume flowrate of inside the ith branch
stp_conv	: Convergence criterion to stop iteration
SI	: International System of Units
ε	: Pipe internal surface roughness
μ	: Dynamic viscosity of the fluid inside the piping system
ρ	: Density of the fluid inside the piping system

3 ANALYSIS PROCEDURE

3.1 General

The analysis procedure for the piping network is based on satisfying mass flow conservation to and from the whole network system as well as mass flow conservation through its junctional nodes. Upon achieving the mass flow balance to a satisfactory convergence error, all pressure differentials and volumetric flowrates are determined across all network branches as well as defining the nodal pressure values.

3.2 Concept

The concept of analysis is to implement Hardy-Cross method of mass flowrate conservation over the junctional nodes of the network. Those junctional nodes are automatically numbered based on the sequential numbering of the network branches with their inlet and outlet nodes' numbers. Further, their unknown pressure heads are initially guessed, in a gradual manner, according to the user-input terminal nodes' conditions (pressures and/or volumetric flowrates) to initiate the iterative process on which the implemented method is based.

3.3 Calculations

The detailed calculations of Hardy-Cross method and the related iterative procedure are referenced to [1]. These calculations account for flow type, laminar or turbulent, within each branch of the designed network and ensure mass conservation based on the user-defined convergence criterion.

ATTENTION: Set g = 1 when using Imperial/English units.

4 ANALYSIS ROUTINE

4.1 General

The analysis procedure is translated into a computer routine to calculate the flowrates magnitudes and directions through all branches, total pressure differentials along branches and pressure heads at all network nodes.

4.2 User Input File

For the computer routine to perform the analysis correctly,

1) The user needs to input the required information as described in the template of Table 4-1.
2) The user needs to maintain the sequence of line numbers as specified without being altered.
3) Maintenance of units' consistency for all input parameters is important.

Upon generating the input file, considering the above-mentioned conditions, the user is to save this file as "17010001301030000101.txt" in the same folder of the executable file.

Table 4-1: Template for user-input parameters

1	ε								
2	μ								
3	ρ								
4	g								
5	stp_conv								
6	itermax								
$0^{(b)}$	----------$^{(a)}$								
7	1	nam-1$^{(d)(e)}$	nd_in-1	pf_in-1$^{(f)}$	nd_out-1	pf_out-1$^{(f)}$	ID_1	L_1	ns_1 $^{(g)}$
8	2	nam-2$^{(d)(e)}$	nd_in-2	pf_in-2$^{(f)}$	nd_out-2	pf_out-2$^{(f)}$	ID_2	L_2	ns_2 $^{(g)}$
:	:	:	:	:	:	:	:	:	:
$n+6^{(c)}$	n	nam-n$^{(d)(e)}$	nd_in-n	pf_in-n$^{(f)}$	nd_out-n	pf_out-n$^{(f)}$	ID_n	L_n	ns_n $^{(g)}$
$0^{(b)}$	----------$^{(a)}$								
n+7	$1^{(i)}$	H_1							
n+8	$2^{(i)}$	H_2							
:	:	:							
$nd+n+6^{(h)}$	$nd^{(i)}$	H_{nd}							
$0^{(b)}$	----------$^{(a)}$								

(a) These dashes are field separators and need to be input as is (10 dashes).

(b) This "0" is a controlling line index for the routine to read input parameters properly.

(c) The value of "n" depends on the number of branches. The more branches are added, the more lines are added from line "7" till the next controlling line "0".

(d) Name of the branch (optional to user to name it).

(e) Branches can be inserted in any sequence starting at line "7" and ending at the last branch at line "n+6".

(f) Nodal conditions. If terminal node with pre-set pressure, set absolute pressure value. If terminal node with pre-set volumetric flowrate, set flowrate value (+ve) if flow enters branch at Inlet node and (-ve) if flow discharges from branch at inlet node (same value but opposite sign at outlet node even if junctional). The opposite is applicable for pre-set volumetric flowrate terminal nodes, as outlet nodes. Otherwise, it is a junctional node with a set value of (-1).

(g) Nodal boundary condition index. 0: if junctional node, 1: if terminal node with pre-set pressure, 2: if terminal node with pre-set flowrate.

(h) The value of "nd" depends on the number of nodes within the network.

(i) Node indexes must be listed in sequence from 1 to nd

4.3 Output File

Upon the execution of the computer routine, the following information are extracted in the output file "17010001311030000101.txt":

1) The branch number (i) , the branch name (as defined by user), its flowrate $\dot{Q}_i$, its head drop h_i, in terms of pressure drop, along it, the direction of the flow and the node index from/to which the flow direction is defined.

2) The node number (j) and its corresponding absolute pressure (P_j), excluding nodal elevation.

Further, a log file is generated broadcasting the status of the routine execution as to whether completed successfully or terminated due to some errors in the input file information.
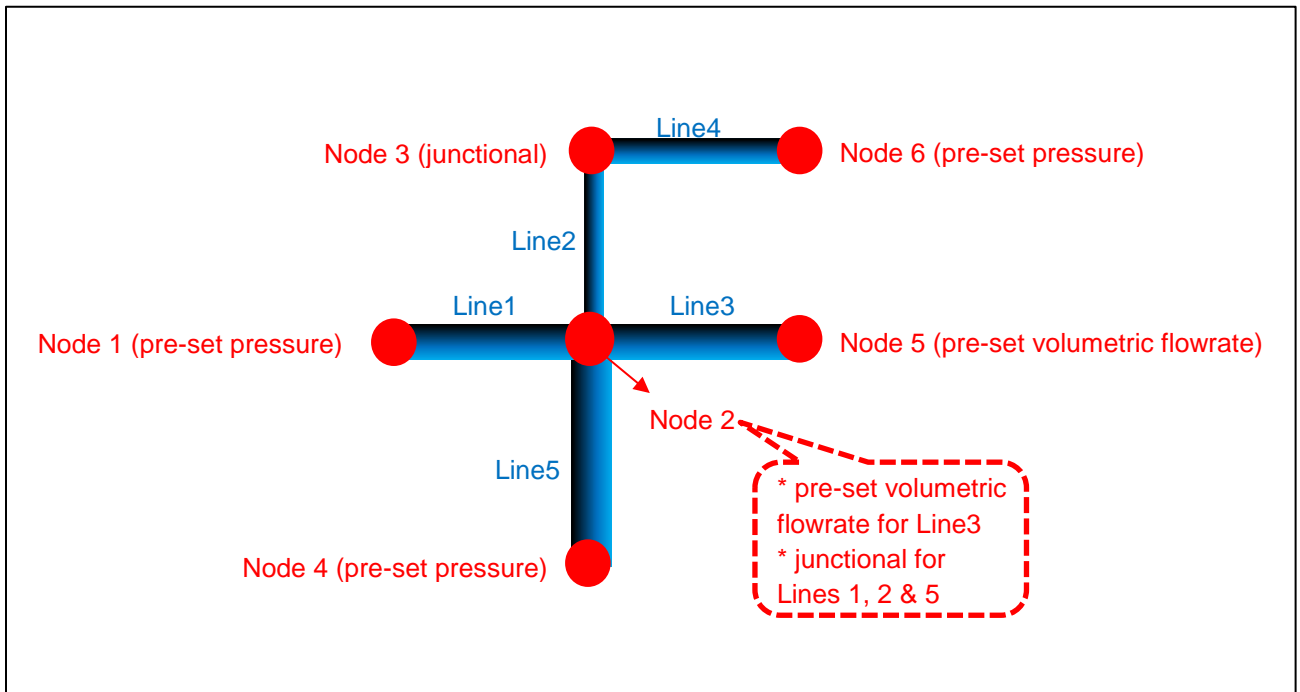
4.4 Sample Problem

A sample problem is presented herein to familiarize the user with the computer routine and to evaluate its capability in handling similar analysis problems. The problem is to calculate the flowrates and nodal pressures of a 5-branch network with random nodal elevations. The details of the piping network are listed in Table 4-2, in SI units system, which are to be input by the user in the input file. Figure 4-1 illustrates a schematic of the analyzed network.

Table 4-2: Input parameters of the sample problem

1	0.00085									
2	0.00089									
3	1000									
4	9.81									
5	1.e-7									
6	600000									
0	----------									
7	1	Line1	1	5.e5	2	-1	0.075	500	1
8	2	Line2	2	-1	3	-1	0.025	600	0
9	3	Line3	2	0.002	5	-0.002	0.075	800	2
10	4	Libe4	3	-1	6	1.e5	0.03	300	1
11	5	Line5	2	-1	4	1.5e5	0.075	600	1
0	----------									

12	1	0						
13	2	10						
14	3	5						
15	4	30						
16	5	20						
17	6	25						
0	----------							

Figure 4-1: Schematic of sample problem network

Upon the execution of the computer routine for the input file, as detailed in Table 4-2, the pressure drops and flowrates along all branches are listed in Table 4-3.

Table 4-3: Branches results of the sample problem

Branch No.	Branch Name	Flowrate	Pressure Difference		
1	Line1	0.275E-02	0.526E+05	Flow direction from node	1
2	Line2	0.165E-03	0.853E+05	Flow direction from node	2
3	Line3	0.200E-02	0.448E+05	Flow direction from node	2
4	Line4	0.165E-03	0.163E+05	Flow direction from node	3
5	Line5	0.588E-03	0.588E+04	Flow direction from node	2

The nodal pressures, excluding effect of nodal elevations, are listed in Table 4-4.

Table 4-4: Nodal pressures results of the sample problem

Node	Pressure
1	0.500E+06
2	0.349E+06
3	0.312E+06
4	0.150E+06
5	0.206E+06
6	0.100E+06

As can be observed, the enforced flowrate through (Line3) remains as set and the discharge flowrate through (Line4) is identical to that through (Line2).

5 REFERENCES

[1] CNAT Doc. No.: 1701000110003000010A, "Piping Network Manual".